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# THERMAL EXPANSION OF TUNGSTEN

BY

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*Bureau of Standards*

December 1, 1925


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# THERMAL EXPANSION OF TUNGSTEN

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# THERMAL EXPANSION OF TUNGSTEN

By Peter Hidnert and W. T. Sweeney

ABSTRACT

This paper gives the results of an investigation on the thermal expansion of tungsten (99.98 per cent) over various temperature ranges between −100 and +500° C. A summary of available data obtained by previous observers on the thermal expansion of tungsten is included. The expansion of tungsten is given by the following empirical equation:

$$L_t = L_o[1 + (4.28\ t + 0.00058\ t^2)10^{-6}]$$

where $L_t$ represents the length of the metal at any temperature $t$ between −105 and +502° C., and $L_o$ the length at 0° C. Average coefficients of expansion for various temperature ranges are given in a table.

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## I. INTRODUCTION

The pioneer experiments of Fink on the linear thermal expansion of tungsten were followed by the work of Langmuir, Worthing, and other investigators. A summary of the results [1] of these researches is given in Table 1.

The present research was undertaken for the purpose of obtaining reliable data on the linear thermal expansion of pure tungsten. Expansion determinations were made over various temperature ranges between −100 and +500° C.

The authors wish to express their appreciation for the tungsten furnished by the Fansteel Products Co., North Chicago, Ill. Acknowledgment is also due to Dr. W. Souder, Bureau of Standards, for valuable suggestions.

[1] With reference to determinations made on tungsten filaments, C. W. Balke, chemical director of the Fansteel Products Co., states that most tungsten filaments contain up to three-fourths of 1 per cent of thorium oxide.

TABLE 1.—*Summary of expansion data on tungsten by previous observers*

| Observer | Date | Material | Temperature or temperature range | Coefficient of linear expansion per degree centigrade | Expansion equation |
|---|---|---|---|---|---|
| | | | °C. | ×10⁻⁶ | |
| Fink [1] | 1910 | Tungsten wire 0.005 inch diameter | 20 to 100 | 3.36 | |
| Fink [2] | 1913 | Tungsten | | 4.3 | |
| Langmuir [3] | 1916 | Tungsten filament | 1,000 to 1,500 | [4] 3.8 | $\frac{\Delta L}{L}=0.00245\left(\frac{T-300}{1{,}000}\right)+0.000367\left(\frac{T-300}{1{,}000}\right)^2$, where $T$ is any temperature between 1,200 and 2,500° K., and $L$ the length at 300° K. |
| | | | 1,500 to 2,000 | [4] 4.4 | |
| | | | 1,000 to 2,000 | [4] 4.1 | |
| Worthing [5] | 1916 | Tungsten filaments of large cross section. | [6] 27 | [4] 4.5 | $\frac{L-L_{300}}{L_{300}}=4.49\times10^{-6}(T-300)+2.4\times10^{-13}(T-300)^3$, where $L$ represents the length at a temperature $T$ between 1,200 and 2,700° K. and $L_{300}$ the length at 300° K. |
| | | | 1,000 to 1,500 | [4] 5.6 | |
| | | | 1,500 to 2,000 | [4] 6.6 | |
| | | | 1,000 to 2,000 | [4] 6.1 | |
| Gray, Schad, and Hidnert [7] | 1917 | Tungsten rod, 5.6 mm diameter, density [8] 19.211 g/cm³ at 17° C.; made from pure tungsten powder (probably 99.98 to 99.99 per cent tungsten) by Fansteel Products Co., Chicago, Ill. | −100 to 0 | 4.1 | $L_t=L_o[1+(4.20\ t+0.00111\ t^2)10^{-6}]\pm10.1\times10^{-6}$, where $L_t$ is the length at any temperature $t$ between −140 and +328° C. and $L_o$ the length at 0° C. |
| | | | 0 to 100 | 4.3 | |
| | | | 0 to 200 | 4.4 | |
| | | | 0 to 300 | 4.5 | |
| Worthing [9] | 1917 | Tungsten filament | 27 | 4.44 | $\frac{L-L_o}{L_o}=4.44\times10^{-6}(T-300)+4.5\times10^{-11}(T-300)^2+2.20\times10^{-13}(T-300)^3$, where $L_o$ and $L$, respectively, refer to the lengths at 300° K. and at the temperature $T$ between 300 and 2,700° K. |
| | | | 1,027 | 5.19 | |
| | | | 2,027 | 7.26 | |
| Disch [10] | 1921 | Tungsten from Glühlampenwerk der Siemens und Halske A.-G. in Charlottenburg. | −190 to 0 | [4] 3.8 | $L_t=L_o[1+(4.46\ t+0.00073\ t^2)10^{-6}]$ between 0 and 400° C.<br>$L_t=L_o[1+(4.45\ t+0.00328\ t^2)10^{-6}]$ between −190 and +20° C. |
| | | | −100 to 0 | [4] 4.1 | |
| | | | 0 to 100 | [4] 4.5 | |
| | | | 0 to 200 | [4] 4.6 | |
| | | | 0 to 300 | [4] 4.7 | |
| | | | 0 to 400 | [4] 4.8 | |
| Goucher [11] | 1924 | Tungsten wires [12] | | | |

[1] Fink, Trans. Amer. Electrochem. Soc., 17, p. 229; 1910.
[2] Fink, Journ. Ind. and Eng. Chem., 5, p. 8; 1913.
[3] Langmuir, Phys. Rev. 7, p. 302; 1916.
[4] Computed from expansion equation.
[5] Worthing, Journ. Frank. Inst., 181, p. 857; 1916.
[6] The expansion equation also represents the coefficient of expansion at room temperature (300° K.).
[7] Unpublished work at Bureau of Standards.
[8] Determined by H. W. Bearce, of the Bureau of Standards.
[9] Worthing, Phys. Rev., 10, p. 638; 1917.
[10] Disch, Zeits. f. Physik, 5, p. 173; 1921.
[11] Goucher, Phil. Mag., 48, p. 229; 1924.
[12] Goucher's expansion data and conclusions regarding transformation points appear to be erroneous and inconsistent with the work of other investigators.

## II. APPARATUS

Figure 3 of Bureau of Standards Scientific Paper No. 497 shows part of the apparatus used in this investigation. A detailed description will appear in a forthcoming scientific paper of this bureau on the Thermal Expansion of Fused Silica.

## III. RESULTS

A rod of pure tungsten,[2] 4.5 mm in diameter and 300 mm in length, was used in this investigation. The density[3] was 19.211

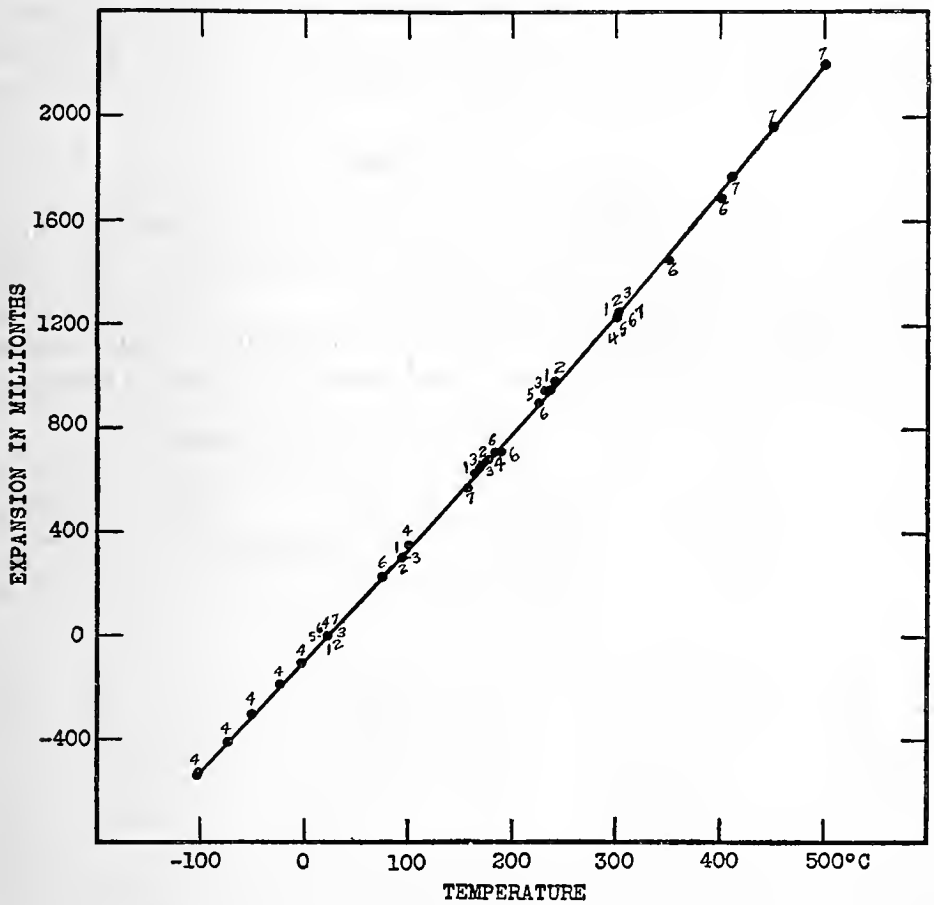


FIG. 1.—*Linear expansion of tungsten (99.98 per cent)*

g/cm³ at 25° C. After the expansion determinations the chemical composition[4] of the tungsten rod was found to be as follows: Molybdenum, 0.015 per cent; copper, 0.005 per cent; arsenic, less than 0.002 per cent; bismuth, antimony, tin, and vanadium not detected; tungsten, 99.978 per cent (by difference). Direct determination of tungsten gave values between 99.90 and 100.00 for tungsten.

[2] For preparation, see Jones, Chem. and Met. Eng., 22, p. 9; 1920.
[3] Determined by Miss E. E. Hill, of this bureau.
[4] Determined by H A. Bright, of this bureau.

Seven expansion tests were made on the rod of tungsten for the following temperature ranges: Tests 1, 2, 3, and 5 each from about 23 to 300° C.; test 4 from −105 to +302° C.; test 6 from 21 to 402° C., and test 7 from 21 to 502° C. All tests except 6 and 7 were made in the oil bath shown at the extreme right of the figure mentioned in the preceding section. The air furnace marked BS18625 in the same figure was used for tests 6 and 7. The seventh test was not carried beyond the maximum temperature indicated in order to prevent oxidation of the sample.

The observations of all tests on heating, reduced to an initial temperature of 23° C., are represented graphically in Figure 1. The numbers on the observations refer to the tests. From these data the following empirical equation was derived by the method of least squares:

$$L_t = L_o\,[1 + (4.28\,t + 0.00058\,t^2)\;10^{-6}]$$

where $L_t$ represents the length of the metal at any temperature $t$ between −105 and +502° C., and $L_o$ the length at 0° C. The probable error of $L_t$ is $\pm 0.000008\,L_o$.

The average coefficients of expansion for various temperature ranges given in Table 2 were computed from the preceding equation.

TABLE 2.—*Average coefficients of expansion of tungsten*

| Temperature range (in degrees centigrade) | Average coefficients of expansion per degree centigrade | Temperature range (in degrees centigrade) | Average coefficients of expansion per degree centigrade |
|---|---|---|---|
| | × 10⁻⁶ | | × 10⁻⁶ |
| −100 to −50 | 4.2 | −100 to 0 | 4.2 |
| −50 to 0 | 4.3 | 0 to 100 | 4.3 |
| 0 to +50 | 4.3 | 0 to 200 | 4.4 |
| +50 to 100 | 4.4 | 0 to 300 | 4.5 |
| 100 to 200 | 4.5 | 0 to 400 | 4.5 |
| 200 to 300 | 4.6 | 0 to 500 | 4.6 |
| 300 to 400 | 4.7 | −100 to 500 | 4.5 |
| 400 to 500 | 4.8 | | |

The observations on cooling generally lie below the expansion curve on heating. The maximum deviation between the observations on heating and cooling did not exceed 0.003 per cent in any test. For the fifth, sixth, and seventh tests the deviation was less than 0.001 per cent.

Figure 2 gives a comparison of the expansion curve (applicable from 0° C.) obtained in the present investigation with data from previous investigators for the temperature range between −100 and +500° C. The values of Gray, Schad and Hidnert, and Worthing agree closely with the results of this research. Fink's value lies below the curve, and Disch's values at the high temperatures lie above the curve.

## IV. SUMMARY

This paper gives the results of an investigation on the thermal expansion of tungsten (99.98 per cent) over various temperature ranges between −100 and +500° C.

A summary of available data obtained by previous observers on the thermal expansion of tungsten is included.

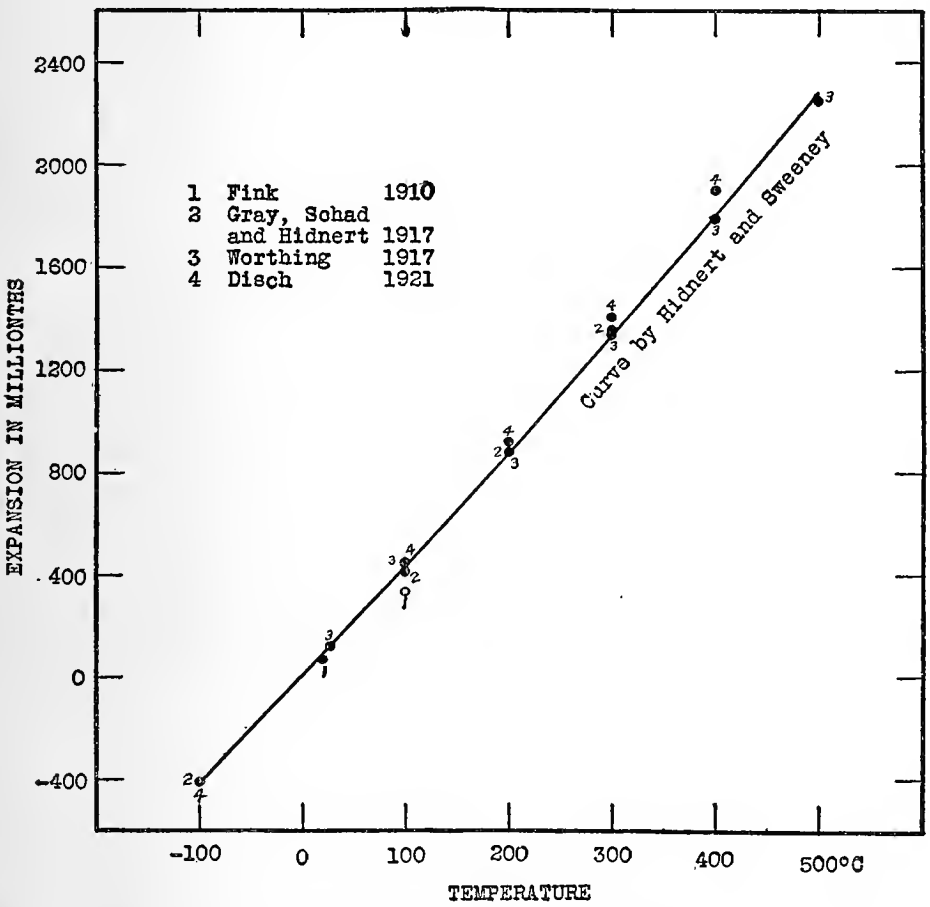


FIG. 2.—*Comparison of expansion curve obtained in the present investigation on tungsten with data from previous observers*

The expansion of tungsten is given by the following empirical equation:

$$L_t = L_o[1 + (4.28\ t + 0.00058\ t^2)10^{-6}]$$

applicable between −105 and +502° C.

The coefficients of expansion increase regularly with temperature. From 0 to 500° C. the average coefficient of expansion is $4.6 \times 10^{-6}$ per degree centigrade. Table 2 gives additional coefficients of expansion for various temperature ranges.

WASHINGTON, August 17, 1925.